

Stock Composition of Arctic Grayling in the Upper Gulkana River, 2002

by
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March 2007

Alaska Department of Fish and Game

Divisions of Sport Fish and Commercial Fisheries



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Weights and measures (metric)		General		Measures (fisheries)	
centimeter	cm	Alaska Administrative		fork length	FL
deciliter	dL	Code	AAC	mid-eye-to-fork	MEF
gram	g	all commonly accepted		mid-eye-to-tail-fork	METF
hectare	ha	abbreviations	e.g., Mr., Mrs., AM, PM, etc.	standard length	SL
kilogram	kg			total length	TL
kilometer	km	all commonly accepted			
liter	L	professional titles	e.g., Dr., Ph.D., R.N., etc.	Mathematics, statistics	
meter	m			<i>all standard mathematical</i>	
milliliter	mL	at	@	<i>signs, symbols and</i>	
millimeter	mm	compass directions:		<i>abbreviations</i>	
		east	E	alternate hypothesis	H _A
		north	N	base of natural logarithm	<i>e</i>
		south	S	catch per unit effort	CPUE
		west	W	coefficient of variation	CV
		copyright	©	common test statistics	(F, t, χ^2 , etc.)
		corporate suffixes:		confidence interval	CI
		Company	Co.	correlation coefficient	
		Corporation	Corp.	(multiple)	R
		Incorporated	Inc.	correlation coefficient	
		Limited	Ltd.	(simple)	r
		District of Columbia	D.C.	covariance	cov
		et alii (and others)	et al.	degree (angular)	°
		et cetera (and so forth)	etc.	degrees of freedom	df
		exempli gratia		expected value	<i>E</i>
		(for example)	e.g.	greater than	>
		Federal Information		greater than or equal to	≥
		Code	FIC	harvest per unit effort	HPUE
		id est (that is)	i.e.	less than	<
		latitude or longitude	lat. or long.	less than or equal to	≤
		monetary symbols		logarithm (natural)	ln
		(U.S.)	\$, ¢	logarithm (base 10)	log
		months (tables and		logarithm (specify base)	log ₂ , etc.
		figures): first three		minute (angular)	'
		letters	Jan,...,Dec	not significant	NS
		registered trademark	®	null hypothesis	H ₀
		trademark	™	percent	%
		United States		probability	P
		(adjective)	U.S.	probability of a type I error	
		United States of		(rejection of the null	
		America (noun)	USA	hypothesis when true)	α
		U.S.C.	United States	probability of a type II error	
			Code	(acceptance of the null	
		U.S. state	use two-letter	hypothesis when false)	β
			abbreviations	second (angular)	"
			(e.g., AK, WA)	standard deviation	SD
				standard error	SE
				variance	
				population	Var
				sample	var
Weights and measures (English)					
cubic feet per second	ft ³ /s				
foot	ft				
gallon	gal				
inch	in				
mile	mi				
nautical mile	nmi				
ounce	oz				
pound	lb				
quart	qt				
yard	yd				
Time and temperature					
day	d				
degrees Celsius	°C				
degrees Fahrenheit	°F				
degrees kelvin	K				
hour	h				
minute	min				
second	s				
Physics and chemistry					
all atomic symbols					
alternating current	AC				
ampere	A				
calorie	cal				
direct current	DC				
hertz	Hz				
horsepower	hp				
hydrogen ion activity	pH				
(negative log of)					
parts per million	ppm				
parts per thousand	ppt, ‰				
volts	V				
watts	W				

FISHERY DATA REPORT NO. 07-07

**STOCK COMPOSITION OF ARCTIC GRAYLING IN THE UPPER
GULKANA RIVER, 2002**

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ABSTRACT

The purpose of this study in 2002 was to collect length and age composition data from the Arctic grayling population in portions of the upper Gulkana River, to compare length and age composition estimates with historic data collected in 1990 to 1992, and to determine if the management objective of providing a sport fishery where large fish ≥ 320 mm FL could be caught with regularity was being met. The sampling protocol in terms of the distribution of effort, areas sampled, and gear type (hook-and-line gear) used during 1990 to 1992 was repeated in 2002. To determine if a representative sample of the population was attained, the sampling protocol and testing procedures required to satisfy the five assumptions of a two-event mark-recapture experiment for a closed population were applied. A total of 598 Arctic grayling were sampled using a 4-person crew during two events, June 26 to June 29 and July 9 to July 10. Although abundance estimates were obtained for two of the four areas sampled, the sampling protocol and testing procedures failed to demonstrate that a representative sample of the entire population of Arctic grayling in the upper Gulkana River was attained. Therefore, the length and age composition was not estimated and changes in the population's composition could not be evaluated. Instead, historical comparisons and the assessment of the management goal were limited to analyzing catch compositions. The proportion of fish ≥ 320 mm FL sampled in 2002 was nearly three times greater than in 1990, 1991, or 1992, and in 2002 the sampling crew crews experienced similar, or better catch rates than experienced in the early 1990s. Therefore, the management goal of providing an Arctic grayling fishery where large fish can be caught with regularity is deemed to be met and further research is not necessary in the short term.

Key words: Arctic grayling, *Thymallus arcticus*, abundance, age composition, length composition, hook-and-line, mark-recapture, catch composition, Gunn Creek, Lower Fish Lake, Gulkana River, Alaska.

INTRODUCTION

The Gulkana River originates in the Alaska Range and flows approximately 154 km to the Copper River (Figure 1). Historically, the Gulkana River has supported one of the largest Arctic grayling *Thymallus arcticus* fisheries in the State of Alaska (Howe and Fleischman 2001) and is the largest Arctic grayling fishery in the Upper Copper/Upper Susitna Management Area (Taube and Sarafin 2001). From 1991 to 2000, annual catch averaged 10,749 fish and annual harvests averaged 3,628 fish (Taube and Sarafin 2001). Most of the fishing effort has been directed at Arctic grayling in the mainstem Gulkana River from the outlet of Paxson Lake to Sourdough Creek and most of the remaining effort has been directed at Arctic grayling in select waters (Gunn Creek, Lower Fish Lake, and portions of the East Fork Gulkana River) of the upper Gulkana River, which is defined as all waters upstream from Paxson Lake (Figure 2). Within the upper Gulkana River, aside from Summit Lake, effort, harvest, and catch statistics are unreliable and imprecise because the numbers of respondents to the Statewide Harvest Survey have been too small (i.e., 0 to 6 respondents), or because detailed location descriptions within the upper Gulkana River by respondents have been lacking. For example, estimates of catch in Gunn Creek have ranged from zero fish in 1991 (2 respondents) to 1,715 fish in 1990 (6 respondents).

Numerous Arctic grayling stock assessment investigations have been conducted on the mainstem Gulkana River between Paxson Lake and Sourdough Creek (Williams and Potterville 1983; Roth and Delaney 1987; Roth and Alexandersdottir 1990; Vincent-Lang and Alexandersdottir 1990; Bosch 1995); however the only work conducted in the upper Gulkana River was a multi-year mark-recapture experiment (1991-1992) designed to estimate abundance of Arctic grayling (Bosch 1995). In this experiment, Arctic grayling were sampled during three sampling events (June and July 1991, August-September 1991, and June-August 1992) in four discrete areas, Gunn Creek, Gunn Lake, Lower Fish Lake, and a short reach of East Fork Gulkana River

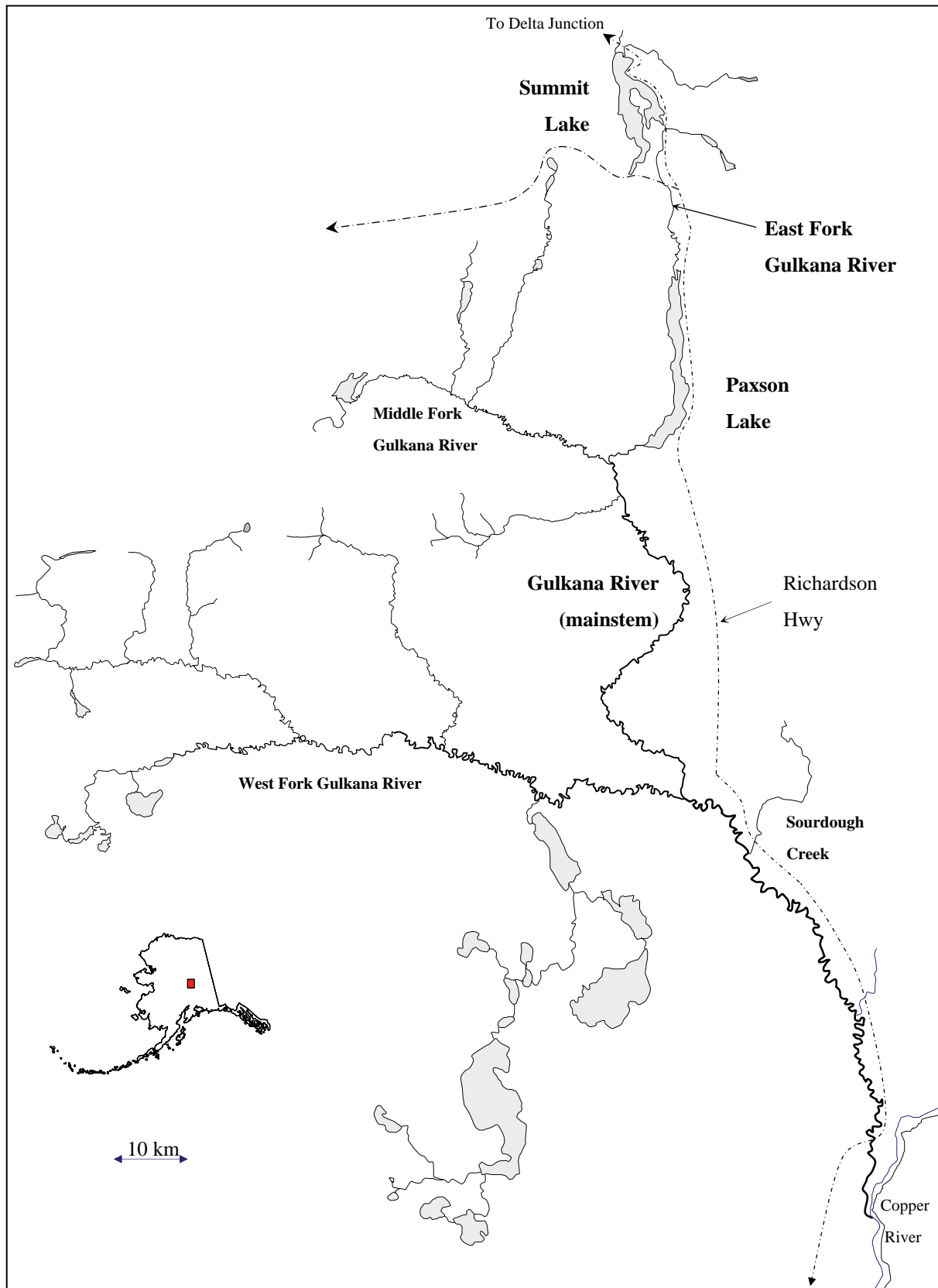


Figure 1.—Gulkana River drainage.

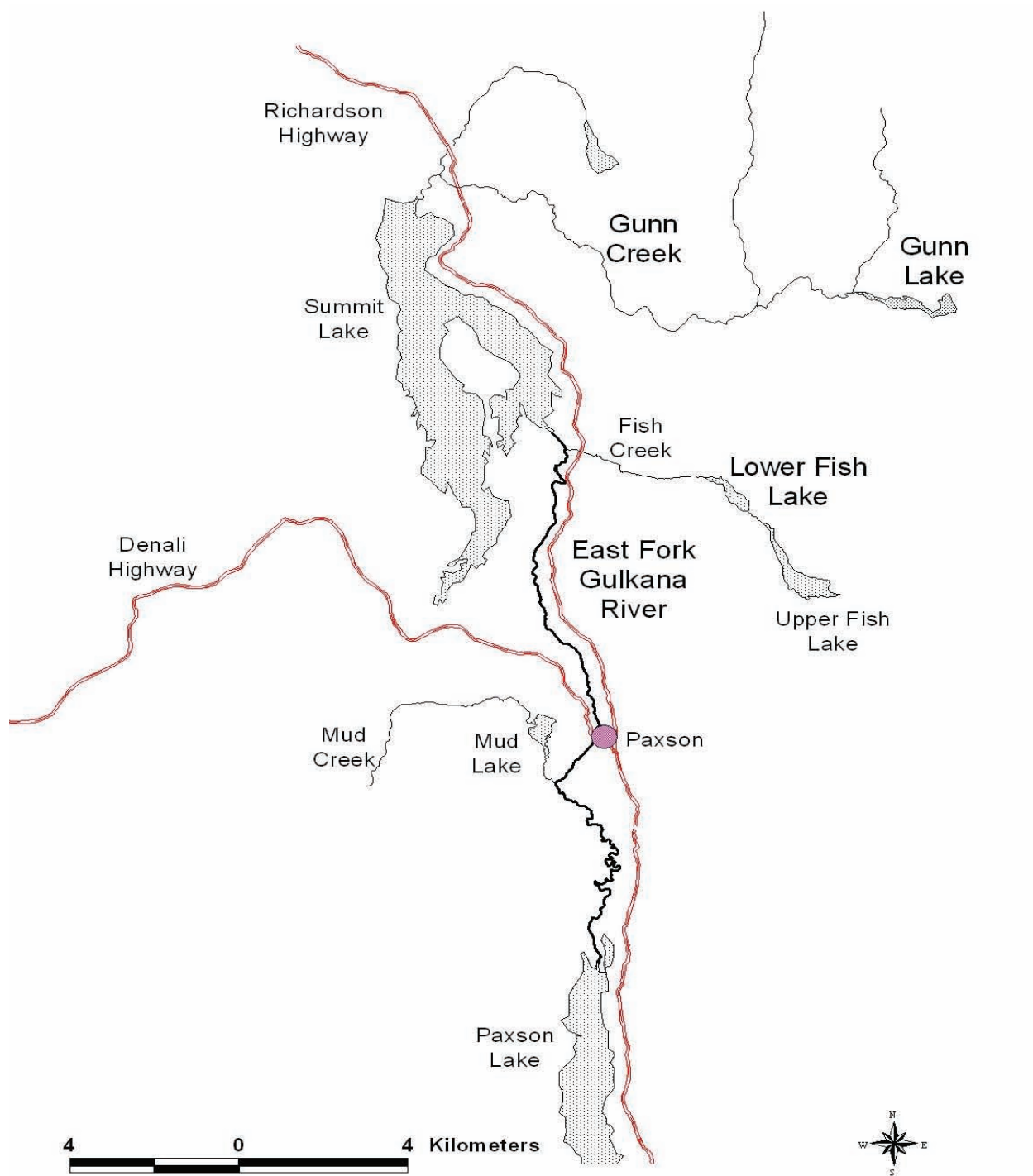


Figure 2.—Upper Gulkana River drainage.

(approximately 2 km in length) below the outlet of Summit Lake (fish sampled in 1990 were not included in the estimate because of insufficient sample sizes). The resultant Jolly-Seber model based estimate of abundance (Seber 1982) was 5,329 (SE = 2,133) fish. This estimate was not considered germane to all waters upstream of Paxson Lake, but rather an estimate of the number of Arctic grayling residing in the areas that were sampled (Bosch 1995). Bosch (1995) described these waters as being unique because they were the only roadside-accessible areas in the Gulkana River drainage where trophy-sized fish (≥ 18 -in TL) could be caught with regularity.

Based on Bosch's (1995) findings of population structure and the management objective to maintain a fishery with high catch rates of large fish, the regulatory structure was changed in 1996 from a 5-fish daily bag limit (only one of which could be greater than 14 in) to a regulation that allowed for catch-and-release fishing only.

This study was undertaken to prepare for the Board of Fisheries meeting held in December of 2002 in anticipation of proposals to reinstate the harvest of Arctic grayling in the upper Gulkana River and because stock status data had not been collected in this area since 1992. The intent of this study was to collect length and age composition data from Arctic grayling in those areas sampled by Bosch during 1991 and 1992 and to determine the population's status relative to the management goal of providing a fishery where large fish could be caught with regularity. At a minimum, it was intended that the composition of the catch in 2002 would be compared with those from 1991 and 1992 and that catch data would be used to assess whether additional research was warranted for evaluating the management goal. The sampling protocols established by Bosch (1995) were followed with the thought that controlling for factors that could affect the length composition of the catch such as gear selectivity and distribution of sampling effort, if the length composition of population differed by sampling area, would support the argument of using the catch composition as an index for assessing the change in the composition of the population. However, it was recognized that catch comparisons would be of limited value primarily because the approach neither tests nor corrects for size selective sampling and, as a result, the catch composition can not be assumed to be representative of the population's composition.

It was recognized that a mark-recapture experiment was needed to provide a means to test and correct for size selective sampling and heterogeneities in capture probabilities due to spatio-temporal effects. However, the resources (i.e., man hours) needed to fully support a study design that would ensure an unbiased and relatively precise abundance estimate were not available. Therefore, the sampling protocol for a mark-recapture experiment was adapted to fit within the framework of following Bosch's sampling protocol (sampling limited areas) in the hope that the experiment would nevertheless meet model assumptions and yield unbiased, even if imprecise, estimates. If successful, the mark-recapture experiment would provide a baseline results for future comparisons and, provided that a reanalysis of Bosch's data yielded comparable results, the experiment would be used to more appropriately compare the population(s) length and age compositions among years.

The research objectives of this project were optimistic in that their success was contingent upon a successful mark-recapture experiment (Task 1) and a comparable result from the reanalysis of Bosch's data (Task 2). If these criteria were not met, the analysis would default to comparing catch compositions to assess whether additional research was warranted for evaluating the management goal.

OBJECTIVES

The research objectives for 2002 were to:

1. estimate the length and age composition of Arctic grayling (≥ 150 mm FL) in the upper Gulkana River drainage that were vulnerable to hook-and-line sampling for 2002 such that all proportions were within 10 percentage points 95% of the time;
2. test the hypothesis that of all Arctic grayling (≥ 150 mm FL) vulnerable to hook-and-line gear in the upper Gulkana River drainage in 2002, the proportion of fish > 319 mm FL was similar to the proportion captured in 1991 and 1992 such that a 10% difference in the proportions could be detected with $\alpha=0.1$ and $\beta=0.2$; and,
3. test the hypothesis that of all Arctic grayling (≥ 150 mm FL) vulnerable to hook-and-line gear in the upper Gulkana River drainage in 2002, the proportion of fish \geq age-5 was similar to the proportion captured in 1991 and 1992 such that a 10% difference in the proportions could be detected with $\alpha=0.1$ and $\beta=0.2$.

Additional project tasks were to:

1. analyze the 2002 data to determine if the abundance of Arctic grayling in the upper Gulkana drainage could be estimated to at least within 50% of the true abundance 95% of the time;
2. determine the length composition of Arctic grayling (≥ 150 mm FL) in the upper Gulkana River drainage that were vulnerable to hook-and-line sampling for 1991 and 1992;
3. summarize the 1991, 1992, and 2002 length and age data by four geographic sampling areas: 1) the East Fork, which includes the 16-km section of the Gulkana River between Summit and Paxson lakes; 2) Gunn Creek; 3) Gunn Lake; and, 4) Lower Fish Lake; and,
4. test the hypothesis that the length composition of Arctic grayling vulnerable to hook-and-line gear in the upper Gulkana River drainage was similar between the four geographic sampling areas within sampling years, 1991, 1992, and 2002.

The phrase “vulnerable to hook-and-line gear” refers to the entire range of sizes/ages that can be captured with conventional angling gear. Typically the smallest size of fish the gear can catch is between 100 and 150 mm FL (usually ages 1-2), if these smaller-sized fish are present in the population. However, hook-and-line gear is more effective at capturing larger (e.g., >270 mm FL) Arctic grayling (Gryski 2004). Thus, the hook-and-line sample was not expected to be representative of true population proportions.

Achieving the objectives was contingent upon a successful mark-recapture experiment (Task 1) and a comparable result from the reanalysis of Bosch’s data (Task 2). In lieu of a successful mark-recapture experiment Objective 1 would, in effect, default to “calculating the length and age composition of the catch” (i.e., rather than “estimating the compositions of the population”). In addition, the hypothesis tests (Objectives 2 and 3), which were developed as a basis for managers to evaluate the management goal of providing for high catch rates of large fish, would not be valid without a successful mark-recapture experiment. The hypothesis tests would also not be valid (and not performed) if the reanalysis of Bosch’s data (Task 2) failed to yield estimates of population parameters rather than catch compositions. Relative to this fishery, a

large fish was defined as being ≥ 14 in TL or ≥ 320 mm FL (T. Taube, Area Manager, ADF&G, Glennallen; personal communication). Comparing proportions of fish age-5 and older (Objective 3) was meaningful because the average length of age-5 Arctic grayling in Bosch's (1995) study was 333 mm. Therefore these ages represent what are considered large fish.

Relative to Task 1, estimating the abundance was not included as an objective because, given limited resources, there was not a high degree of confidence that a large enough fraction of the population could be sampled to achieve precision goals. The precision goals of this task did not dictate sample size requirements. Task 2 was included because a comparable summary of length data was not included in Bosch (1995). Tasks 3 and 4 were included to gain some understanding of the spatial variability in length and age composition.

METHODS

STUDY AREA

The Upper Gulkana River drainage is comprised of four distinct areas: the East Fork Gulkana River, the Lower and Upper Fish lakes area, Gunn Creek drainage, and Summit Lake, which are all utilized differently by anglers. General descriptions are provided for each area, patterns of angler use are described, and the locations within each area sampled by Bosch are identified below. During 1990-1992, each of the four areas were sampled periodically over the duration of the summer by Bosch (1995). For example, in 1991, the Lower Fish Lake was sampled on seven occasions: May 29-30, June 7 to 10, July 2-5, July 30 to 31, August 1-6, August 18-21, and September 2- 4.

The East Fork Gulkana River flows approximately 18 km from the outlet of Summit Lake to Paxson Lake (Figure 2). For the first 11 km the river gradient is steep (approximately 20 m/km), and downstream of this section the gradient decreases abruptly forming a slow-meandering channel until it enters Paxson Lake. Bosch (1995) characterized the first 11 km, which parallels the Richardson Highway, as containing limited habitat in which 20 to 40 Arctic grayling can be captured in a day of angling. Arctic grayling are also known to inhabit the lowermost 7 km, however, little is known about their size composition or density. In 1990-1992, Bosch (1995) sampled within a small 4-km reach within the upper 11 km of the East Fork Gulkana River: an approximately 1-km reach of pool-riffle habitat near the salmon viewing stand, which is located approximately 1 km downstream from the outlet of Summit lake and three pools adjacent to the highway. These three pools (separated by approximately 0.5-km) represented the only fishable water in the stretch below the 1-km pool-riffle reach and a point approximately 3 kilometers downstream. These areas are where anglers typically target Arctic grayling; however, Arctic grayling use the entire reach between Paxson and Summit lakes for feeding and migration.

Fish Creek is a small first-order tributary approximately 4.0 km in length and drains Upper Fish Lake and Lower Fish Lake, which are separated by an approximately 0.5-km reach of stream (Figure 2). Wild sockeye salmon spawn and rear in both of these lakes. Upper Fish Lake is 85 ha in size and has a maximum depth of 9 m, and Lower Fish Lake is approximately 28 ha (approximately 1.4 km in length) and has a maximum depth of 4.5 m (Bosch 1995). Both lakes are situated above tree line at an elevation of 1,044 m. Most anglers target Arctic grayling in Lower Fish Lake and tend to fish from shore near the lake's outlet. Anglers access Lower Fish Lake via a 3.5-km long un-maintained gravel road or trail that is unsuited for highway vehicles.

Bosch (1995) described that of all the areas sampled in the upper Gulkana River, the outlet area of Lower Fish Lake was the only area in which 100 or more Arctic grayling could be sampled in one day. Consequently, most (i.e., > 95%) of his sampling was done in this area. The remainder of Lower Fish Lake was sampled on one occasion each summer, but catches in this area were generally too small (e.g., <10 fish) to warrant further sampling. Upper Fish Lake was sampled once by Bosch, but only about five Arctic grayling were caught (T. Taube, Area Manager, ADF&G, Glennallen; personal communication).

The Gunn Creek drainage is comprised of Gunn Creek and Gunn Lake (Figure 2). Gunn Creek is a small second-order stream approximately 17 km in length situated above tree line that starts at an elevation of approximately 1,300 m and drains into Summit Lake at an elevation of 980 m. The outlet stream of Gunn Lake originates approximately 12 km upstream from Summit Lake. Most anglers access Gunn Creek from the Richardson Highway Bridge crossing by either walking or driving off-road vehicles upstream along undesignated trails and stream banks, which requires periodic fording the stream. Based on field observations by department staff, anglers likely do not go beyond where the stream valley begins to narrow approximately 6 river kilometers upstream of the highway bridge. Bosch (1995) sampled between Summit Lake and a point approximately 6-8 river kilometers upstream.

No surface or depth information is available for Gunn Lake, but based on an inspection of a topographical map it appeared to be similar in size to Upper Fish Lake. Gunn Lake is situated above tree line at an elevation of 1,078 m. According to Bosch (1995), Gunn Lake appears to be too shallow to provide adequate overwintering habitat for fish, as the bottom of the entire lake can be seen from the surrounding ridges. Gunn Lake is thought to receive little to no fishing effort, which is partially attributed to difficult access. Gunn Lake can be accessed via undesignated off-road vehicle trails emanating from Lower Fish Lake, and requires approximately 16 km of overland travel across ridge tops. Bosch (1995) reported that few Arctic grayling appear to use the Gunn Creek/Gunn Lake complex, with a good day of sampling consisting of fewer than 20 fish in either area. Bosch sampled around the lake's perimeter from shore.

Although Summit Lake was not sampled in the early 1990s or in this study, it represents a significant portion of the drainage and is known to be used by upper Gulkana River Arctic grayling as a migratory corridor, and likely for rearing, overwintering and feeding. Bosch (1995) observed movement of tagged Arctic grayling between Gunn Creek and both Lower Fish Lake and the East Fork Gulkana River and thus documented intra and inter-annual movements of Arctic grayling through Summit Lake. However, no studies have been conducted on Arctic grayling within Summit Lake. Thus, the extent to which Summit Lake is used for spawning, feeding, overwintering, or rearing by Arctic grayling is unknown.

SAMPLING DESIGN

At a minimum, this study was designed to describe the length and age composition of the Arctic grayling sampled in the Upper Gulkana River and to determine if additional research would be necessary to assess whether the management goal of providing a fishery where large fish could be caught with regularity was being met. In addition, this study addressed the more ambitious objectives/tasks of estimating the abundance and the length and age compositions of the population and comparing these estimates to population estimates obtained from data collected in the early 1990s (Bosch 1995). The former design requirement was addressed by distributing

the sampling effort among the four sampling areas as allocated by Bosch (1995) and by using similar angling gear to that used by Bosch (1995). The latter design requirement was addressed by attempting (given limited resources) to follow sampling protocols required to satisfy the five assumptions of a two-event mark-recapture experiment designed to estimate abundance and length and age composition of a closed population (Seber 1982).

In 1990-1992, the upper Gulkana River was divided into four sampling areas (Gunn Creek, Gunn Lake, Lower Fish Lake, and a portion of the East Fork Gulkana River) and the sampling crew (a 2- or 3-person crew) expended one workday (approximately 8 h) accessing and sampling each area. In 2002, sampling effort was similarly distributed using two 2-person crews during 2 sampling events (Crews A and B; Table 1). To help ensure that spatial distribution of effort was similarly apportioned among the four sampling areas, a crewmember who assisted with sampling in 1992, assisted with sampling and advised the crews. In addition, consultations were made with the author of the 1990-1992 work prior to commencement of field activities regarding areas sampled and gear used (D. Bosch, Fisheries Biologist, ADF&G, Anchorage; personal communication). The study areas were accessed using a combination of road and off-road vehicles and by walking. All fish were captured using hook-and-line gear. Fishing was conducted from shoreline (lakes) and by wading (streams). The same angling gear employed by Bosch (1995) was used: spin and fly fishing gear with terminal gear consisting of an assortment of spinners and dry flies. In 2002, rubber-bodied jigs were also used. The choice of terminal gear was left to the discretion of each angler, however, at least one crewmember fished with fly-fishing gear while sampling.

In the first event (27-30 June), fish ≥ 150 mm FL were marked (primary) with an individually-numbered internal anchor tag. Each fish also received an area-specific secondary mark (fin clip) to detect and mitigate effects of tag loss and infer movement in the event of tag loss. In the second event (9-12 July), fish were not tagged, but were given an upper caudal fin clip to avoid double counting.

The abundance in 2002 was to be estimated using a two-event Petersen mark-recapture experiment (Seber 1982) designed to satisfy the following assumptions:

1. the population was closed (fish do not enter or leave the population during the experiment);
2. all Arctic grayling had a similar probability of capture in the first event or in the second event, or marked and unmarked Arctic grayling mixed completely between the first and second events;
3. marking of Arctic grayling in the first event did not affect the probability of capture in the second event;
4. marked Arctic grayling were identifiable during the second event; and,
5. all marked Arctic grayling were reported when examined during the second event.

Table 1.—Distribution of sampling effort in the upper Gulkana River study area, 2002.

Date	Crew	Area	Description of Area Sampled
6/27	A and B	Gunn Creek	Between Summit Lake to a point approximately 6.8 river kilometers upstream. Each crew was assigned to a portion of the creek, which was fished systematically while wading upstream.
6/28	A and B	Lower Fish Lake	All fishing occurred within an approximately 200 m radius from the outlet of Fish Lake. Within this radius Crew A angled the northern shore and Crew B the southern shore.
6/29	A and B	Gunn Lake	Gunn Lake. Effort was primarily focused on the NW shoreline and the inlet and outlet areas. The northern shore was intermittently fished.
6/30	A and B	East Fork Gulkana River	The same portions of the East Fork Gulkana River targeted by Bosch (1995) as previously described were sampled.
7/9	A and B	Gunn Creek	Between Summit Lake to a point approximately 6.8 river Kilometers upstream. Each crew was assigned to a portion of the creek, which was fished systematically while wading upstream.
7/10	A and B	Lower Fish Lake	The outlet area was sampled and both the northern and southern shorelines were intermittently fished up to the inlet. Effort was also directed at a spring located at the NE corner of the Lake
7/11	A	Lower Fish Lake.	The outlet area was sampled and both the northern and southern shorelines were intermittently fished up to the inlet. Effort was also directed at a spring located at the NE corner of the Lake
7/11	B	Gunn Lake	Gunn Lake. Effort was primarily focused on the NW shoreline and the inlet and outlet areas. The northern shore was intermittently fished.
7/12	A and B	East Fork Gulkana River	The same portions of the East Fork Gulkana River targeted by Bosch (1995) as previously described were sampled.
7/12	A	Gunn Creek	Approximately 2 hours of sampling effort was expended in the lower 2 km of Gunn Creek to increase sample sizes.

Relative to Assumption 1, Bosch (1995) demonstrated that within the entire upper Gulkana River the Arctic grayling population was closed. Movement was expected during the experiment but only on a localized scale (e.g., within 1 km); therefore, the closure assumption was expected to be met within each sampling area. The duration of the study was kept short to render growth recruitment and mortality insignificant. Location data for recaptured fish were examined for evidence of movement to evaluate the appropriateness of the assumption of closure.

Relative to Assumption 2, it was expected that all fish within the upper Gulkana River were unlikely to be subjected to equal probabilities of capture during either event due to hydrologic and habitat differences in the four sampling areas (e.g., lakes vs. a moderate sized river vs. a small stream) and because the distribution of effort was not expected to be in proportion to relative abundances among areas. However, the probability of capture was expected to be similar with respect to spatial and temporal factors within each of the four sampling areas because effort would be applied in close proportion to abundance within an area. Mixing among the four sampling areas was not expected; therefore, a geographically stratified estimator was anticipated. Diagnostic tests to identify heterogeneous capture probabilities and methods to correct for potential biases are presented below.

Relative to Assumption 3, a hiatus of 11 days between the first and second events in a given sampling area was included to allow marked fish the time to recover from the effects of being captured and handled and to resume their normal behavior. In addition, the use of active gear and two different types of terminal gear when angling served to mitigate potential marking-induced effects in behavior (e.g., gear avoidance).

Relative to Assumptions 4 and 5, Arctic grayling captured during the first event were double-marked with an internal anchor tag and an area-specific fin clip, and all fish caught in the second event were carefully examined for marks.

DATA COLLECTION

All captured Arctic grayling were processed immediately or soon after capture and released at or within approximately 50 m of their capture location. After each fish was caught, crews collected and recorded data for date, location, crew, fork length, scale samples, fin clips, tag number, tag color, recapture status, and mortality. Two scales were removed for aging from all fish and stored in coin envelopes. Data were recorded in field notebooks. These data were later entered into an Excel spreadsheet for analysis and archival.

Scales were taken for aging from the area approximately six scale rows above the lateral line just posterior to the insertion of the dorsal fin (Brown 1943). Scales were processed by wiping slime and dirt off each scale and mounting them on gummed cards. The gummed cards were used to make triacetate impressions of the scales (30 s at 137,895 kPa, at a temperature of 97°C). Ages were determined by counting annuli from the triacetate impressions magnified to 40X with a microfiche reader. The presence of an annulus was determined as described by Kruse (1959).

DATA ANALYSIS

Abundance Estimate

It was anticipated that a geographically stratified Petersen estimator (a combination of Chapman and Bailey modified estimators for lakes and river sections, respectively) would be used to estimate abundance. As it will be demonstrated, an insufficient number of Arctic grayling

recaptured in two of the four areas led to an area-specific analysis. For each section, violations of Assumption 2 relative to size-selective sampling were tested for using two Kolmogorov-Smirnov (K-S) tests. There were four possible outcomes of these two tests relative to evaluating size selectivity (either one of the two samples, both, or neither of the samples could be biased) and two possible actions for abundance estimation (length stratify or not). The tests and possible actions for data analysis are outlined in Appendix A1. Temporal and spatial violations of Assumption 2 were tested for using consistency tests described by Seber (1982; Appendix A2). If all three of these tests rejected the null hypothesis, then a partially or completely stratified estimator must be used. If movements of marked fish between strata were observed (incomplete mixing), the methods of Darroch (1961) would be used to compute a partially stratified abundance estimate. If no movements of marked fish between geographic strata were observed, a completely stratified abundance estimate would be computed using the methods of Bailey (1951, 1952) or Darroch (1961). Otherwise, at least one of the three consistency tests will fail-to-reject the null hypothesis and it will be concluded that at least one of the conditions in Assumption 2 was satisfied. Criteria considered when defining geographic strata included number of recaptures per stratum and physical characteristics of the system. When estimating abundance a minimum number of recaptures (approximately 7 fish) were preferred to permit reliable diagnostic testing and to ensure negligible statistical bias in \hat{N} (Seber 1982).

Re-analysis of 1990-1992 Data

Objectives 2 and 3 and Tasks 2-4 required that archived data from 1990-1992 be recovered with sufficient detail to test for size selectivity within each geographic section. These data sets were gathered and examined as to which relevant objectives and tasks could be performed. For purposes of documentation and comparing catch samples, data from sampling efforts in 1990 were included in the analysis.

Length and Age Composition Estimates

The length and age composition analysis would take two different forms depending on the outcomes of the mark-recapture experiment and the re-analysis of the 1990-1992 data: 1) comparisons could be of population parameters if outcomes were successful; or, 2) comparisons of catch compositions if these efforts were not successful. As will be described, results precluded performing analyses described in Objectives 2 and 3 and Tasks 2-4 and resulted in the comparison of the length composition of catches. For the 2002 data, length compositions among the four areas within a sampling event were tested for homogeneity using an Anderson-Darling test (A-D; Scholz and Stephens 1987). The 1990-1992 length data were summarized by cumulative length frequency distributions and A-D tests were performed to test homogeneity of length compositions among each of the four areas in each of the years 1990-1992. In addition, pairwise comparisons of length composition data were performed among areas within year and among years within area using K-S tests. Mean lengths at age were determined using all Arctic grayling caught in the study area during 2002 according to methods described in Appendix A4.

For the two areas for which an abundance estimate was possible, the length and age compositions of those discrete populations were estimated using methods described in Appendix A4.

RESULTS

During 2002, a total of 598 Arctic grayling were sampled: 351 from Lower Fish Lake, 114 from Gunn Creek, 99 from East Fork Gulkana River, and 34 from Gunn Lake (Table 2). The smallest recaptured fish from Lower Fish Lake was 320 mm FL, no fish were recaptured in Gunn Lake, the smallest recaptured fish in the East Fork Gulkana River was 315 mm FL, and in Gunn Creek the smallest was 322 mm FL. Even if all of the M-R assumptions had been met (presented below) having not recaptured any small fish (i.e., <320) precluded use of these results for estimating the abundance of smaller fish or for estimating the proportion of large fish in the Upper Gulkana River drainage. As a result, Objectives 1-3, and Task 1 could not be accomplished.

Table 2.—Summary of catch statistics by sampling area in the Upper Gulkana River, 2002.

	# Marked	# Examined	# Recaptured
Sampling Area	(n ₁)	(n ₂)	(m ₂)
Gunn Creek	47	67	16
Lower Fish Lake	198	153	12
Gunn Lake	20	14	0
East Fork Gulkana	56	43	3
All areas	321	277	31

ABUNDANCE ESTIMATES BY GEOGRAPHIC AREA

Gunn Lake and East Fork Gulkana River

Examination of the results demonstrated that the abundance of large Arctic grayling could not be estimated within Gunn Lake or in the East Fork Gulkana River due to small numbers of recaptured fish and assumption violations. In Gunn Lake no fish were recaptured in the second event. Within the East Fork Gulkana River only three fish were recaptured and closure could not be ensured. After sampling this area it became very evident that fish movement, even on a localized scale of 1 km, would likely have resulted in fish moving between the small reaches of water sampled (i.e., < 1.5 kilometers in total) and the adjacent stream sections or Summit Lake.

Gunn Creek

Abundance was estimated for fish ≥ 320 mm FL (14 in TL) within a 6.9-km sampling area in Gunn Creek. The lower length bound was selected because below this length only one fish (314 mm FL) was recaptured and this length category related directly to the definition of large fish expressed in the management goal. During the experiment, 37 fish ≥ 320 mm FL were marked during the first event (n₁), 48 were examined during the second event (n₂), and 14 fish marked in the first event were recaptured in the second event (m₂; Table 3).

Table 3.—Number of Arctic grayling ≥ 320 mm FL marked (n_1), examined (n_2), and recaptured (m_2) by geographic section within the 6.8-km sampling area of Gunn Creek.

Section Where Marked	Section Where Recaptured					m_2	n_1	$n_1 - m_2$	$P_{\text{capture 2st Event}} (m_2/n_1)$
	1 ^a (1.0 km)	2 (1.3 km)	3 (1.4 km)	4 (1.2 km)	5 (1.9 km)				
1	1	0	0	0	0	1	3	2	0.33
2	0	2	0	2	0	4	10	6	0.40
3	0	0	1	2	1	4	9	5	0.44
4	0	0	0	0	4	4	11	7	0.36
5	0	0	0	0	1	1	4	3	0.25
n_2	2	4	8	19	15				
m_2	1	2	1	4	6				
$n_2 - m_2$	1	2	7	15	9				
$P_{\text{capture 1st Event}} (m_2/n_2)$	0.50	0.50	0.13	0.21	0.40				

^a Section 1 is adjacent to Summit Lake and Section 5 is the farthest upstream section.

For fish ≥ 320 mm FL, the sampling design and the results of the testing procedures (Appendices A1 and A2) determined that stratification by size or area was not required and that the Bailey-modified Petersen estimator (Bailey 1951 and 1952; Appendix A3) be used to estimate abundance. Size-selective sampling for Arctic grayling ≥ 320 mm FL was not apparent during the experiment. K-S tests failed to reject the null hypothesis of no difference between the length compositions of fish ≥ 320 mm FL marked in the first event and those examined in the second event ($D = 0.15$; $P\text{-value} = 0.68$; Figure 3). Also, K-S tests failed to reject the null hypothesis of no difference between the length compositions of Arctic grayling ≥ 320 mm FL marked in the first event and those recaptured during the second event ($D = 0.26$; $P\text{-value} = 0.41$; Figure 3). These results indicated a Case I situation (Appendix A1) for which there was no need to stratify abundance estimates by size, and lengths and ages from both events were combined to estimate length and age compositions (Appendix A4). The tests of consistency were conducted at two geographic scales: the first using all five sections, and the second pooling sections 1-3 and 4-5 to create 2 strata that divided the study area roughly in half. At both scales, first event and second capture probabilities did not significantly differ ($P\text{-values} \geq 0.43$; Table 3), and the null hypothesis for complete mixing was not rejected ($P\text{-value} = 0.085$).

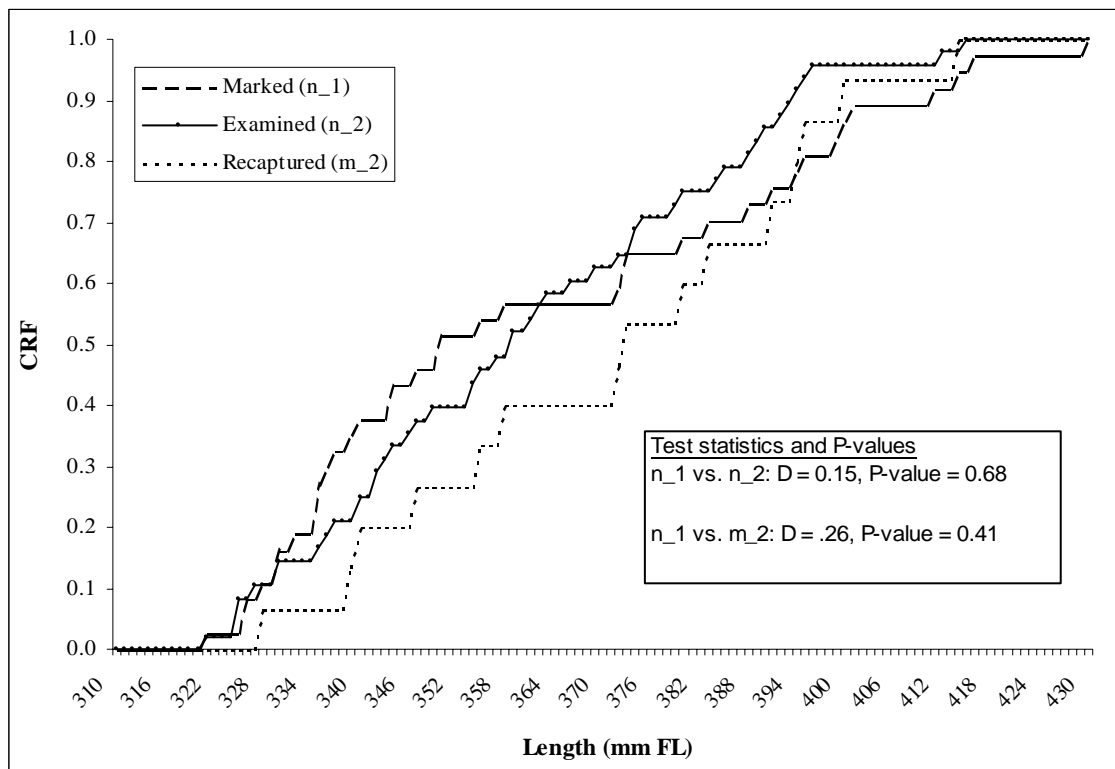


Figure 3.—Comparisons of cumulative relative length frequencies (CRF) of Arctic grayling ≥ 320 mm FL marked in the first event, examined in the second event, and marked fish recaptured in the second event within the 6.8-km Gunn Creek sampling area, 2002.

Relative to the assumption of closure, there was evidence of emigration upriver out of the study area, and limited evidence to support no immigration into the study area from Summit Lake between sampling events. Of the 14 recaptured fish, nine (64%) had moved upstream one or two sections and none had moved downstream (Table 3). Evidence for no immigration was that in the lower two sections there were very few fish observed or captured during the second event (i.e., only six fish were captured in sections 1 and 2), and first event capture probabilities (i.e., 0.50) in these two areas were high relative to upriver areas, which led to the expectation that, if present, the Arctic grayling would have been caught. Although the evidence to support no immigration is not strong (e.g., fish could have immigrated from Summit Lake through the lower sections and into the upper sections) it nevertheless suggests the abundance estimate may be unbiased relative to the time of the first event. However, even if significant immigration occurred in conjunction with emigration the estimate would be biased positive and serve as an upper limit on abundance.

The estimated abundance of Arctic grayling ≥ 320 mm FL in the lower 6.9 km of the sampling area was 121 (SE = 25) during the time of marking. Of fish ≥ 320 mm FL within the Gunn Creek sampling area, most were age-5 or older and < 360 mm FL (Appendices B1 and B2).

Fish Lake

During the first event, only the area within 200 meters of the lake outlet was sampled (consistent with 1990-1992 studies) and although sampling occurred in areas other than the lake outlet area during the second event, the effort was not systematically distributed around the entire lakes perimeter (i.e., $\leq 50\%$ of the shoreline was fished), nor was the middle of the lake sampled. Although sampling performed during each event was not done in a way expected to subject all Arctic grayling to equal probability of capture, mixing was sufficient enough to result in satisfying Assumption 2. Specifically, the null hypothesis of equal probability of capture between the lake outlet and the remainder of the lake during the first event was not rejected (P-value = 0.15). It was not possible to perform the tests for complete mixing and for equal probability of capture during the second event because sampling did not occur away from the outlet during the first event.

Size-selective sampling for Arctic grayling ≥ 320 mm FL was not apparent during the experiment. K-S tests failed to reject the null hypothesis of no difference between the length compositions of fish ≥ 320 mm FL marked in the first event and those examined in the second event ($D = 0.10$; P-value = 0.51; Figure 4). Also, K-S tests failed to reject the null hypothesis of no difference between the length compositions of Arctic grayling ≥ 320 mm FL marked in the first event and those recaptured during the second event ($D = 0.25$; P-value = 0.53; Figure 4). These results indicated a Case I situation (Appendix A1) for which there was no need to stratify the abundance estimate by size, and lengths and ages from both events were combined to describe length and age compositions (Appendix A4).

The abundance of Arctic grayling ≥ 320 mm FL in Fish Lake was estimated as 1,135 (SE = 295); however, given the possibility that mixing was not complete and the limitations with respect to the distribution of sampling effort, an unknown portion of the population may not have been subjected to non zero probability of capture in either event resulting in a negative bias. As a result the estimate should be viewed as a minimum abundance. Most of the population of Arctic grayling ≥ 320 mm FL was age-5 or older and < 360 mm FL (Appendices B3 and B4).

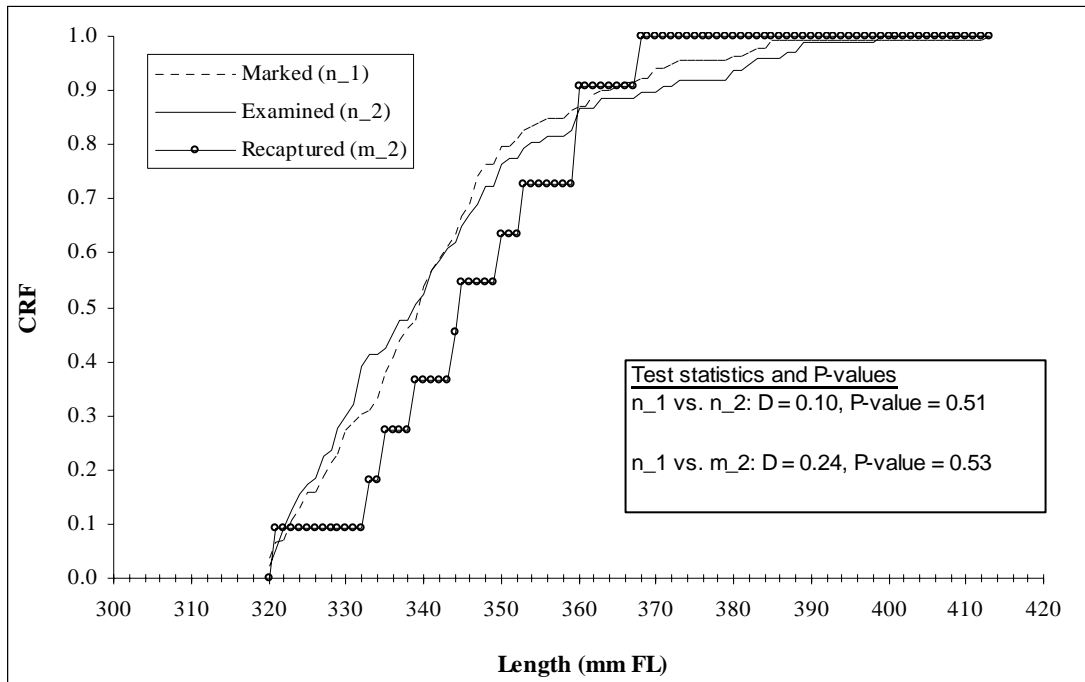


Figure 4.– Comparisons of cumulative relative length frequencies (CRF) of Arctic grayling ≥ 320 mm FL marked in the first event, examined in the second event, and marked fish recaptured in the second event within Lower Fish Lake, 2002.

RE-ANALYSIS OF 1990-1992 DATA

Objectives 2 and 3 and Tasks 2-4 required that the archived data be recovered with sufficient detail to test for size selectivity. The edited data set and accompanying analysis by Bosch (1995) were not available nor were there any attendant field notes. The only data available were the unedited scanned mark-sense forms and missing from the forms were the accompanying “batch sheets” that serve as a key for non-standardized field options on the mark-sense forms. These data sets were examined to determine which objectives and tasks could be performed. The examination revealed that none of the summary statistics (e.g., number of fish marked, examined, or recaptured) presented by Bosch (1995) could not be recreated from the raw data set. Therefore, it was unclear which data (i.e., fish lengths and ages) should be used in attempting to estimate historical length and age compositions. As a result, the analysis focused on the length composition of catches. Moreover, because specific location data were not available, fish sampled from Gunn Creek and Gunn Lake could not be differentiated. Therefore, to make inter-annual comparisons, the Gunn Creek and Gunn Lake samples were consolidated and named Gunn Creek drainage. In an effort to construct reasonably comparable catch samples between 1990, 1991, 1992 and 2002, only those fish that were sampled during the summer feeding period when populations are less likely to move were selected from the archived data files, which would help to control for temporal variation in the length composition of the population(s). Therefore, for all years only those fish sampled from the last week of June, or during July and August were used to contrast length frequency distributions of the catch among years and sampling areas. During 1990 to 1992, some sampling was conducted during late May and early June when fish were likely spawning or migrating to summer feeding areas and in

September when fish were potentially moving towards overwintering areas, although these fish accounted for less than 10% of all fish sampled. Age data for fish sampled in 1992 were not available in the archived data.

COMPARISONS OF CATCH SAMPLES

A-D tests indicated that the length compositions of fish in 2002 among the four sampling areas were dissimilar during each sampling event (Figure 5; Table 4). Within each of the sampling areas significant differences in length compositions of all fish sampled were observed between the first and second events with the exception of Gunn Creek (Table 4; Figure 6).

Within each of the three comparable sampling areas, Gunn Creek drainage, Fish lakes, and East Fork Gulkana River, there were significant differences in cumulative length compositions for fish ≥ 150 mm FL among the four sampling years 1990 – 1992 and 2002 (all P-values ≤ 0.001 ; Figure 7). Among all pair-wise annual comparisons within a sampling area (e.g., Lower fish Lake 1991 vs. Lower Fish Lake 1992), the only failure to reject the null hypothesis of no difference was observed within the Gunn Creek drainage for fish sampled in 1991 versus 1992 (D=0.087, P-value=0.70).

For fish ≥ 150 mm FL, the proportion of fish sampled that were ≥ 320 mm FL was greater in 2002 than in 1990-1992 when lengths from all sampling areas were pooled (Figure 8). Within each of the sampling areas, the proportion of fish sampled ≥ 320 mm FL was also greatest in 2002, except that within Gunn Creek drainage, 1992 was similar to 2002 (Appendices C1-C3). Similarly, more Arctic grayling \geq age-5 were caught in 2002 than in 1990 and 1991 – ages from 1992 were not recoverable in the archived data files (Appendix B5). The mean length of age-5 fish sampled in 2002 was 321 mm FL (SD=29; Appendix C4).

DISCUSSION

The intent of the study design was to attain a representative sample of the population of Arctic grayling in the upper Gulkana River using hook-and-line gear, as described by Bosch (1995) to evaluate the population's status relative to a management goal of providing a fishery where large fish could be caught with regularity and to compare the population structure to that observed in 1990-1992. However, the results of the study failed to demonstrate that a representative sample of the population was attained in 2002, nor was there sufficient information available in the 1990-1992 data to investigate size-selectivity and consequentially address the attendant objectives and tasks.

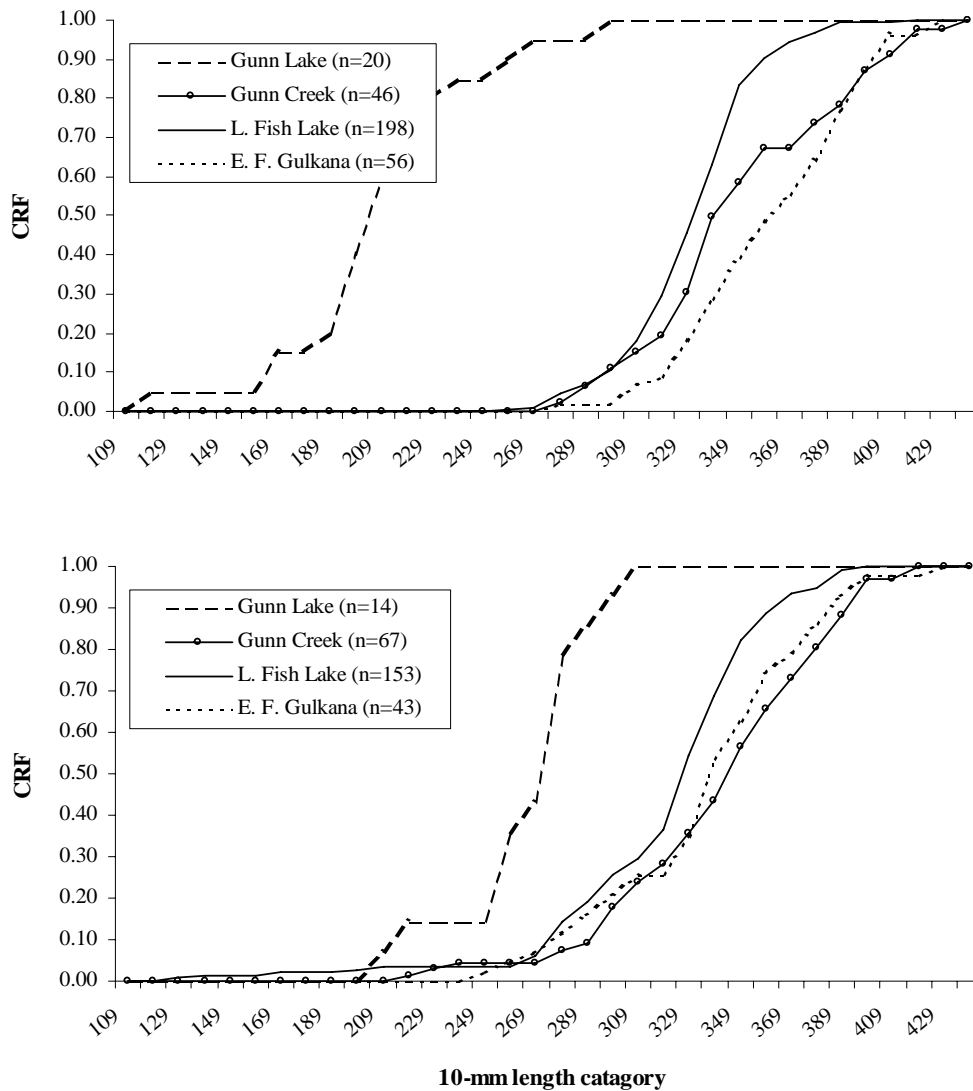


Figure 5.– Comparisons of cumulative relative length frequencies (CRF) of sampled Arctic grayling: 1) between sampling areas during the first event (upper graph); and, 2) between sampling areas during the second event (lower graph) within the upper Gulkana River study area, 2002.

Table 4.–Statistical comparisons of length composition in the upper Gulkana River study area, 2002.

Comparison	Test statistic	P-value
Gunn C. vs. E.F. Gulkana vs. Lower Fish L. (n_1) ^a	A2kn = 24.56	0.000
Gunn C. vs. E.F. Gulkana vs. Lower Fish L. (n_2) ^a	A2kn = 9.00	0.000
East Fork Gulkana River (n_1 vs n_2)	D = 0.297	0.018
Lower Fish Lake (n_1 vs n_2)	D = 0.15	0.036
Gunn Lake (n_1 vs n_2)	A2kn = 7.1	0.001
Gunn Creek (n_1 vs n_2)	D = 0.14	0.533

^a Gunn Lake was omitted from the comparison because of the it's large observed difference in length composition compared to the other three areas (Figure 5) and after pairwise K-S tests identified these differences as significant.

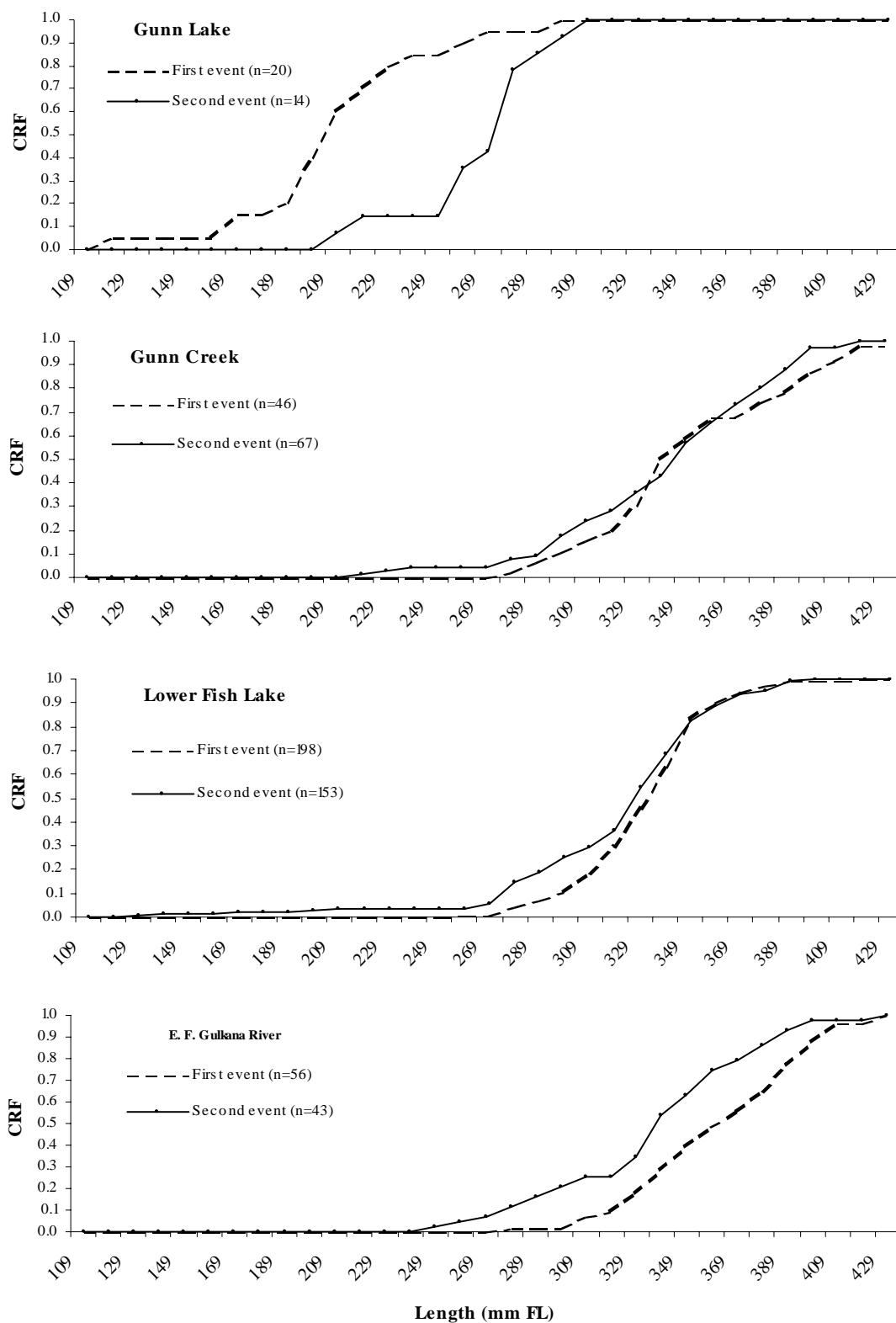


Figure 6.—Comparisons of cumulative relative length-frequency distributions (CRF) of all Arctic grayling sampled during the first event versus the second event by sampling area within the upper Gulkana River study area, 2002.

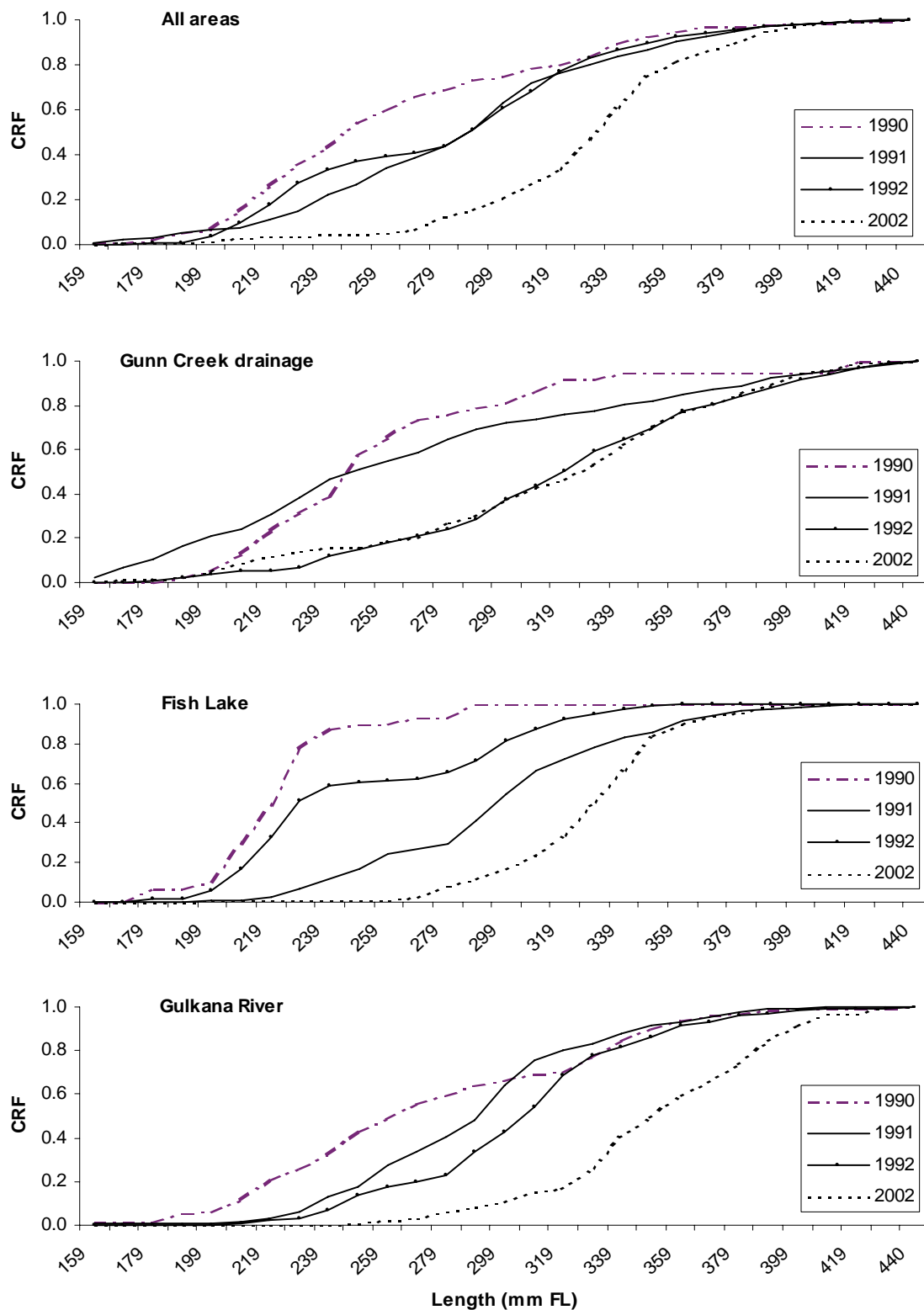


Figure 7.—Interannual comparisons for all areas combined and by sampling area of cumulative relative length frequencies (CRF) of Arctic grayling ≥ 150 mm FL sampled within the upper Gulkana River study area, 2002.

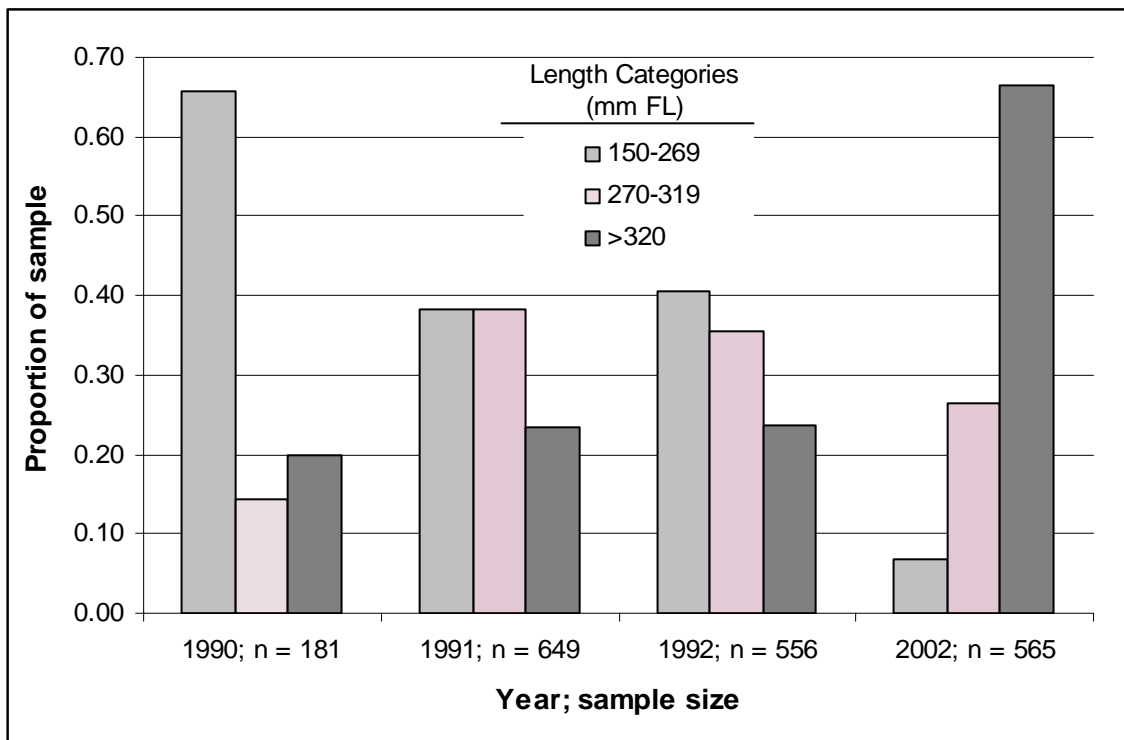


Figure 8.—Proportions of Arctic grayling ≥ 150 mm FL by length category sampled from the upper Gulkana River study area 1990-1992 (Bosch 1995) and during 2002.

Interpretation of the data collected in this study or in prior years is limited in that no definitive inferences can be made about the size or age composition of the Arctic grayling population within the entire upper Gulkana River study area. The data, however, can arguably be used to interpret whether the management goal is being achieved. Bosch (1995) described the upper Gulkana as one of the few places within the Copper River basin where trophy-sized (≥ 18 in TL or 420 mm FL) Arctic grayling could be caught with some regularity, and also characterized good catch rates (number of fish caught per day for a two or three person crew) for each of the four sampling areas: Gunn Greek and Gunn Lake (20 fish per day); Lower Fish Lake (100 fish per day); and, the East Fork Gulkana River (40 fish per day). During 2002, sampling conditions were good (clear water and no rain) and the crews experienced similar or better catch rates, and overall captured a higher proportion of larger-sized fish than in the early 1990s demonstrating the catch rates of large fish have not diminished, and may have improved. Therefore, the management goal of providing an Arctic grayling fishery where large fish can be caught with regularity appears to be met and further research is not necessary in the short term.

It is recommended that a management plan be developed for the upper Gulkana River regulatory area that describes the desired characteristics of the fishery in clearly defined and measurable terms, which would help to develop unambiguous research objectives. For example, descriptions of the fishery could be a specified abundance of fish ≥ 320 mm FL ($\pm 50\%$ C.I) during late June within Lower Fish Lake. Or, if abundance information is not attainable in the short term due to resource constraints, the information collected to date could be used for developing decision criteria for use in determining whether or not resources expenditures to acquire abundance-based

information are warranted. For example, the decision to conduct a mark-recapture experiment at Lower Fish Lake could be required if less than 100 fish ≥ 320 mm FL per day could be caught by two experienced anglers during each of three temporally distinct sample dates (e.g., late June, mid July, and early August). However formulated, it is recommended that the short-term criteria account for: 1) variation in size-selectivity of the gear (i.e., keeping terminal gear consistent); 2) variation in effort by using a defined number of experienced anglers targeting a specific area (e.g., two experienced angler sampling within a 200 meter radius of the outlet of Lower Fish Lake during an 8-hour period); and, 3) temporal variation in the sampled fish population (e.g., due to climatic or hydrologic conditions) by sampling the defined area during two or more distinct periods (e.g., early and late summer). Finally, the management plan should also avoid incorporating the language “vulnerable to hook-and-line gear” because it is ambiguous and subject to interpretation.

Because of the complexity and size of the Arctic grayling habitat in the upper Gulkana River study area, which includes Summit Lake, it is recommended that future within-season 2-event mark-recapture experiments not be directed at estimating total abundance for the entire area to assess the status of the population. Rather developing within-season indices of abundance in areas targeted by anglers such as within the lower 10 km of Gunn Creek or within Lower Fish Lake are more realistic. A multi-year mark-recapture experiment that can account for open system behavior in some portion of the upper Gulkana study area may be feasible, although the cost in resources expended would likely far outweigh the management need.

The East Fork Gulkana River should not be studied for the purpose of estimating abundance because of difficulty in meeting the assumption of closure and the rivers relatively high gradient prohibits sampling in a large majority (i.e., approximately 90%) of the 18-km reach of river. Future studies within the upper Gulkana River study area should also not include Gunn Lake because the lake is not easily accessible, sampling is unproductive, it receives virtually no fishing effort, and the size and abundance of Arctic grayling in the lake is likely consistently small. Therefore, any data collected from this lake would serve as a poor measure of the status of Arctic grayling in the upper Gulkana River utilized by anglers.

No habitat descriptions of Gunn Lake were readily found in developing the study plan and the following brief summary is included to provide documentation of observations. Gunn Lake is a shallow lake and its substrate was almost exclusively (i.e., >80%) covered by thick organic mats of mosses and aquatic plants and their wintertime decomposition would appear to result in unfavorable dissolved oxygen conditions (i.e., ≤ 2.0 mg L⁻¹). In addition, the lake appeared to be heavily influenced by beaver activity at the outlet of the lake. During sampling, a relatively large, unvegetated draw-down area (1-2 m in height) was observed around the lake’s perimeter caused by the dam at the lake’s outlet having been recently breached.

Without a better understanding of the population dynamics of Arctic grayling within the upper Gulkana River, a regulation allowing the harvest of fish is not recommended if the current management goal of providing a fishery where large fish can be caught with regularity remains unchanged. While the upper Gulkana River upstream of Paxson Lake likely contains a large enough population to support some level of sustainable harvest, a regulation allowing harvest would create a risk of localized depletions or reduced catch rates of larger-sized fish (e.g., 14 - 18 in TL) in the vicinity of the few easily accessible areas (i.e., the upper three miles of the East

Fork Gulkana River, Lower reaches of Gunn Creek, and the outlet area of Lower Fish Lake) because Arctic grayling can exhibit a considerable degree of fidelity to summer feeding areas.

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APPENDIX A
MARK-RECAPTURE MODEL ASSUMPTIONS,
TESTS OF ASSUMPTIONS, AND ESTIMATORS

Appendix A1.—Methodologies for alleviating bias due to gear selectivity.

	Result of first K-S test ^a	Result of second K-S test ^b
<u>Case I</u> ^c	Fail to reject H_0 Inferred cause: There is no size-selectivity during either sampling event.	Fail to reject H_0
<u>Case II</u> ^d	Fail to reject H_0 Inferred cause: There is no size-selectivity during the second sampling event, but there is during the first sampling event.	Reject H_0
<u>Case III</u> ^e	Reject H_0 Inferred cause: There is size-selectivity during both sampling events.	Fail to reject H_0
<u>Case IV</u> ^f	Reject H_0 Inferred cause: There is size-selectivity during the second sampling event; the status of size-selectivity during the first event is unknown.	Reject H_0

a The first K-S (Kolmogorov-Smirnov) test is on the lengths of fish marked during the first event versus the lengths of fish recaptured during the second event. H_0 for this test is: The distribution of lengths of fish sampled during the first event is the same as the distribution of lengths of fish recaptured during the second event.

b The second K-S test is on the lengths of fish marked during the first event versus the lengths of fish captured during the second event. H_0 for this test is: The distribution of lengths of fish sampled during the first event is the same as the distribution of lengths of fish sampled during the second event.

c Case I: Calculate one unstratified abundance estimate, and pool lengths and ages from both sampling event for size and age composition estimates.

d Case II: Calculate one unstratified abundance estimate, and only use lengths and ages from the second sampling event to estimate size and age composition.

e Case III: Completely stratify both sampling events and estimate abundance for each stratum. Add abundance estimates across strata. Pool lengths and ages from both sampling events and adjust composition estimates for differential capture probabilities.

f Case IV: Completely stratify both sampling events and estimate abundance for each stratum. Add abundance estimates across strata. Estimate length and age distributions from second event and adjust these estimates for differential capture probabilities.

Appendix A2.—Tests of consistency for the Petersen estimator (from Seber 1982, page 438).

TESTS OF CONSISTENCY FOR PETERSEN ESTIMATOR

Of the following conditions, at least one must be fulfilled to meet assumptions of a Petersen estimator:

1. Marked fish mix completely with unmarked fish between events;
2. Every fish has an equal probability of being captured and marked during event 1; or,
3. Every fish has an equal probability of being captured and examined during event 2.

To evaluate these three assumptions, the chi-square statistic will be used to examine the following contingency tables as recommended by Seber (1982). At least one null hypothesis needs to be accepted for assumptions of the Petersen model (Bailey 1951, 1952; Chapman 1951) to be valid. If all three tests are rejected, a geographically stratified estimator (Darroch 1961) should be used to estimate abundance.

I. Test for complete mixing^a.

Section Where Marked	Section Where Recaptured				Not Recaptured (n_1-m_2)
	I	II	...	t	
I					
II					
...					
s					

II. Test for equal probability of capture during the first event^b.

	Section Where Examined			
	I	II	...	t
Marked (m_2)				
Unmarked (n_2-m_2)				

III. Test for equal probability of capture during the second event^c.

	Section Where Marked			
	I	II	...	s
Recaptured (m_2)				
Not Recaptured (n_1-m_2)				

-
- ^a This tests the hypothesis that movement probabilities (θ) from section i ($i = 1, 2, \dots, s$) to section j ($j = 1, 2, \dots, t$) are the same among sections: $H_0: \theta_{ij} = \theta_j$.
- ^b This tests the hypothesis of homogeneity on the columns of the 2-by- t contingency table with respect to the marked to unmarked ratio among river sections: $H_0: \sum_i a_i \theta_{ij} = k U_j$, where k = total marks released/total unmarked in the population, U_j = total unmarked fish in stratum j at the time of sampling, and a_i = number of marked fish released in stratum i .
- ^c This tests the hypothesis of homogeneity on the columns of this 2-by- s contingency table with respect to recapture probabilities among the river sections: $H_0: \sum_j \theta_{ij} p_j = d$, where p_j is the probability of capturing a fish in section j during the second event, and d is a constant.

Appendix A3.—Equations for calculating estimates of abundance and its variance using the Bailey and Chapman-modified Petersen estimators.

The Bailey-modified Petersen estimator (Bailey 1951 and 1952) is used when the sampling design calls for a systematic manner and to be used even when the assumption of a random sample for the second sample is false when a systematic sample is taken provided:

- 1) there is uniform mixing of marked and unmarked fish; and,
- 2) all fish, whether marked or unmarked, have the same probability of capture (Seber 1982).

The abundance estimate for Gunn Creek was calculated using the equation:

$$\hat{N} = \frac{n_1(n_2 + 1)}{m_2 + 1}, \quad (\text{A1})$$

where:

n_1 = the number of Arctic grayling marked and released alive during the first event;

n_2 = the number of Arctic grayling examined for marks during the second event;

m_2 = the number of Arctic grayling recaptured during the second event; and

Variance was estimated as (Seber 1982):

$$\hat{V}[\hat{N}] = \frac{n_1^2(n_2 + 1)(n_2 - m_2)}{(m_2 + 1)^2(m_2 + 2)} \quad (\text{A2})$$

The abundance estimate for Fish Lake was calculated using Chapman's modification of the Petersen two-sample model (Seber 1982) as follows:

$$\hat{N} = \frac{(n_2 + 1)(n_1 + 1)}{m_2 + 1} - 1 \quad (\text{A3})$$

where:

n_1 = the number of Arctic grayling marked and released during the first event;

n_2 = the number of Arctic grayling examined for marks during the second event; and,

m_2 = the number of Arctic grayling recaptured in the second event.

Variance of this estimator will be calculated as:

$$\hat{V}ar[\hat{N}] = \frac{(n_1 + 1)(n_2 + 1)(n_1 - m_2)(n_2 - m_2)}{(m_2 + 1)^2(m_2 + 2)} \quad (\text{A4})$$

Appendix A4.–Equations for estimating length and age compositions and their variances for the population.

No size selectivity was identified for Arctic grayling ≥ 320 mm FL for both Gunn Creek and Lower Fish Lake (Case I; Appendix B1) Therefore, population compositions of lengths and ages were estimated using measurements from both sampling events. First the proportions from the sample were calculated:

$$\hat{p}_k = \frac{n_k}{n} \quad (1)$$

where:

\hat{p}_k = the proportion of Arctic grayling that were within age or length class k ;

n_k = the number of Arctic grayling sampled that were within age or length class k and,

n = the total number of Arctic grayling sampled.

The variance of this proportion was estimated as (from Cochran 1977):

$$\hat{V}[\hat{p}_k] = \frac{\hat{p}_k(1 - \hat{p}_k)}{n - 1}. \quad (2)$$

The estimated abundance of age or length k fish in the population was then:

$$\hat{N}_k = \sum_{k=1}^s \hat{p}_k \hat{N}, \quad (3)$$

where:

\hat{N}_k = the estimated abundance of age or length class k ; and,

s = the number of age or length classes.

The variance for \hat{N}_k in this case was estimated using the formulation for the exact variance of the product of two independent random variables (Goodman 1960):

$$\hat{V}[\hat{N}_k] \approx \sum_{k=1}^s \left(\hat{V}[\hat{p}_k] \hat{N}^2 + \hat{V}[\hat{N}] \hat{p}_k^2 - \hat{V}[\hat{p}_k] \hat{V}[\hat{N}] \right). \quad (4)$$

For each identified age class, the mean lengths (mm FL) of fish was estimated as the arithmetic mean length of all fish assigned to the same age:

$$\hat{\bar{L}}_k = \frac{\sum_{j=1}^{n_k} L_{jk}}{n_k} \quad (5)$$

-continued-

where:

L_{jk} = FL (mm) of the j^{th} fish sampled that were age k ; and,

n_k = the number sampled for length that were age k .

The variances of the means were estimated as:

$$\hat{V}\left[\hat{\bar{L}}_k\right] = \frac{\sum_{j=1}^{n_k} \left(L_{jk} - \hat{\bar{L}}_k\right)^2}{n_k(n_k - 1)}. \quad (6)$$

APPENDIX B

Appendix B1.—Estimates of length composition and abundance by 20-mm FL groups for Arctic grayling ≥ 320 mm FL in a 6.8-km index section of Gunn Creek, 2002.

Length Class (mm FL)	n	\hat{p}_k	SE [\hat{p}_k]	\hat{N}_k	SE [\hat{N}_k]
320 – 339	25	0.25	0.04	31	7
340 – 324	27	0.27	0.04	33	8
360 – 349	15	0.15	0.04	18	4
380 – 374	22	0.22	0.04	27	6
400 – 399	9	0.09	0.03	11	3
420 – 424	1	0.01	0.01	1	1
440 – 449	0	0.00	0.00	0	0
Total	99				

Appendix B2.—Estimates of age composition and abundance for Arctic grayling ≥ 320 mm FL in a 6.8-km index section of Gunn Creek, 2002.

Age	n	\hat{p}_k	SE [\hat{p}_k]	\hat{N}_k	SE [\hat{N}_k]
3	0	0.00	0.00	0	0
4	5	0.06	0.02	7	2
5	15	0.17	0.04	21	5
6	31	0.36	0.05	43	10
7	18	0.21	0.04	25	6
8	9	0.10	0.03	13	3
9	3	0.03	0.02	4	1
10	6	0.07	0.03	8	2
11	0	0.00	0.00	0	0
Total	87				

Appendix B3.—Estimates of length composition and abundance by 20-mm FL groups for Arctic grayling ≥ 320 mm FL in Lower Fish Lake, 2002.

Length Class (mm FL)	n	\hat{p}_k	SE [\hat{p}_k]	\hat{N}_k	SE [\hat{N}_k]
320 – 339	115	0.49	0.03	553	145
340 – 324	85	0.36	0.03	409	107
360 – 349	22	0.09	0.02	106	28
380 – 374	13	0.06	0.01	63	17
400 – 399	1	0.00	0.00	5	2
420 – 424	0	0.00	0.00	0	0
440 – 449	0	0.00	0.00	0	0
Total	236				

Appendix B4.— Estimates of age composition and abundance for Arctic grayling ≥ 320 mm FL in Lower Fish Lake, 2002.

Age	n	\hat{p}_k	SE [\hat{p}_k]	\hat{N}_k	SE [\hat{N}_k]
3	2	0.01	0.01	0	0
4	85	0.40	0.03	0	0
5	94	0.44	0.03	11	3
6	22	0.10	0.02	455	120
7	7	0.03	0.01	503	132
8	2	0.01	0.01	118	31
9	0	0.00	0.00	37	10
10	0	0.00	0.00	11	3
11	0	0.00	0.00	0	0
Total	212				

Appendix B5.— Summary statistics of Arctic grayling sampled and aged in the upper Gulkana River study area, in 1990 and 1991 (Bosch 1995) and during 2002. Samples from 1990-1991 are comprised of all fish sampled once during July and August and the sample from 2002 includes all fish that were sampled once during late June and early July.

River	Age	Sample Size(n)			Proportion of Sample		
		1990	1991	2002	1990	1991	2002
E.F. Gulkana							
	2	38	6		0.34	0.07	0.00
	3	37	42	5	0.33	0.46	0.06
	4	11	20	28	0.10	0.22	0.33
	5	14	9	25	0.13	0.10	0.30
	6	7	9	18	0.06	0.10	0.21
	7	3	5	4	0.03	0.05	0.05
	8	1		4	0.01	0.00	0.05
Subtotal		111	91	84	1.00	1.00	1.00
L. Fish Lake							
	1	11	2	3	0.27	0.02	0.01
	2	26	24	1	0.63	0.25	0.00
	3	2	44	42	0.05	0.46	0.13
	4	2	15	130	0.05	0.16	0.41
	5		5	109	0.00	0.05	0.34
	6		3	22	0.00	0.03	0.07
	7			7	0.00	0.00	0.02
	8		1	2	0.00	0.01	0.01
	9		1		0.00	0.01	0.00
Subtotal		41	95	316	1.00	1.00	1.00
Gunn Cr. Drainage ^a							
	1		6	1	0.00	0.05	0.01
	2	7	31	2	0.23	0.24	0.02
	3	16	38	13	0.52	0.29	0.11
	4	5	22	11	0.16	0.17	0.10
	5	2	7	23	0.06	0.05	0.20
	6		11	31	0.00	0.09	0.27
	7	1	5	17	0.03	0.04	0.15
	8		4	9	0.00	0.03	0.08
	9		2	3	0.00	0.02	0.03
	10		2	5	0.00	0.02	0.04
	11		1		0.00	0.01	0.00
Subtotal		31	129	115	1.00	1.00	1.00
Total		183	315	515			

^a Gunn Creek drainage includes samples from both Gunn Creek and Lower Fish Lake.

APPENDIX C

Appendix C1.– Summary of Arctic grayling sampled within the Gunn Creek drainage during 1990 – 1992 (Bosch 1995) and 2002. Samples from 1990-1992 are composed of all fish sampled once during July and August and 2002 fish are all fish that were sampled once during late June and early July.

Length Category	Sample Size (n)				Proportion of Sample			
	1990	1991	1992	2002	1990	1991	1992	2002
100 - 109	0	0	0	0	0.00	0.00	0.00	0.00
110 - 119	0	2	0	1	0.00	0.01	0.00	0.01
120 - 129	0	6	0	0	0.00	0.03	0.00	0.00
130 - 139	1	2	0	0	0.03	0.01	0.00	0.00
140 - 149	0	4	0	0	0.00	0.02	0.00	0.00
150 - 159	0	4	0	0	0.00	0.02	0.00	0.00
160 - 169	0	8	0	2	0.00	0.04	0.00	0.02
170 - 179	0	7	1	0	0.00	0.04	0.01	0.00
180 - 189	1	11	1	1	0.03	0.06	0.01	0.01
190 - 199	1	8	2	4	0.03	0.04	0.02	0.03
200 - 209	3	6	1	5	0.08	0.03	0.01	0.04
210 - 219	4	12	0	4	0.10	0.06	0.00	0.03
220 - 229	3	13	2	3	0.08	0.07	0.02	0.02
230 - 239	3	16	5	2	0.08	0.08	0.05	0.02
240 - 249	7	8	3	0	0.18	0.04	0.03	0.00
250 - 259	3	7	3	4	0.08	0.04	0.03	0.03
260 - 269	3	6	3	2	0.08	0.03	0.03	0.02
270 - 279	1	11	3	8	0.03	0.06	0.03	0.06
280 - 289	1	8	5	4	0.03	0.04	0.05	0.03
290 - 299	1	5	9	10	0.03	0.03	0.08	0.08
300 - 309	2	3	6	7	0.05	0.02	0.06	0.05
310 - 319	2	5	7	5	0.05	0.03	0.07	0.04
320 - 329	0	2	9	9	0.00	0.01	0.08	0.07
330 - 339	1	5	5	12	0.03	0.03	0.05	0.09
340 - 349	0	3	6	11	0.00	0.02	0.06	0.08
350 - 359	0	6	7	8	0.00	0.03	0.07	0.06
360 - 369	0	4	3	4	0.00	0.02	0.03	0.03
370 - 379	0	2	4	7	0.00	0.01	0.04	0.05
380 - 389	0	7	4	5	0.00	0.04	0.04	0.04
390 - 399	0	3	4	7	0.00	0.02	0.04	0.05
400 - 409	0	3	2	2	0.00	0.02	0.02	0.02
410 - 419	2	2	3	4	0.05	0.01	0.03	0.03
420 - 429	0	3	2	0	0.00	0.02	0.02	0.00
430 - 439	0	2	1	1	0.00	0.01	0.01	0.01
440 - 449	0	1	3	0	0.00	0.01	0.03	0.00
450 - 459	0	0	1	0	0.00	0.00	0.01	0.00
460 - 469	0	0	1	0	0.00	0.00	0.01	0.00
470 - 479	0	0	0	0	0.00	0.00	0.00	0.00
Total	39	195	106	132				
<150	1	14	0	1	0.03	0.07	0.00	0.01
150-269	28	106	21	27	0.72	0.54	0.20	0.20
270-319	7	32	30	34	0.18	0.16	0.28	0.26
≥320	3	43	55	70	0.08	0.22	0.52	0.53

Appendix C2.–Summary of Arctic grayling sampled within Lower Fish Lake during 1990 – 1992 (Bosch 1995) and 2002. Samples from 1990-1992 are composed of all fish sampled once during July and August and 2002 fish are all fish that were sampled once during late June and early July.

Length Category	Sample Size (n)				Proportion of Sample			
	1990	1991	1992	2002	1990	1991	1992	2002
100 - 109	0	0	2	0	0.00	0.00	0.01	0.00
110 - 119	1	0	5	0	0.02	0.00	0.02	0.00
120 - 129	3	1	1	1	0.07	0.00	0.00	0.00
130 - 139	6	0	0	1	0.14	0.00	0.00	0.00
140 - 149	1	0	0	0	0.02	0.00	0.00	0.00
150 - 159	0	0	0	0	0.00	0.00	0.00	0.00
160 - 169	0	0	0	1	0.00	0.00	0.00	0.00
170 - 179	2	0	4	0	0.05	0.00	0.01	0.00
180 - 189	0	0	0	0	0.00	0.00	0.00	0.00
190 - 199	1	1	12	1	0.02	0.00	0.04	0.00
200 - 209	6	1	30	1	0.14	0.00	0.11	0.00
210 - 219	6	4	43	0	0.14	0.02	0.15	0.00
220 - 229	9	8	50	0	0.21	0.04	0.18	0.00
230 - 239	3	12	20	0	0.07	0.05	0.07	0.00
240 - 249	1	11	4	0	0.02	0.05	0.01	0.00
250 - 259	0	17	3	1	0.00	0.08	0.01	0.00
260 - 269	1	6	3	5	0.02	0.03	0.01	0.01
270 - 279	0	6	8	20	0.00	0.03	0.03	0.06
280 - 289	2	25	15	12	0.05	0.11	0.05	0.04
290 - 299	0	30	27	17	0.00	0.13	0.10	0.05
300 - 309	0	27	16	21	0.00	0.12	0.06	0.06
310 - 319	0	13	14	33	0.00	0.06	0.05	0.10
320 - 329	0	13	7	57	0.00	0.06	0.03	0.17
330 - 339	0	10	8	54	0.00	0.04	0.03	0.16
340 - 349	0	6	3	59	0.00	0.03	0.01	0.17
350 - 359	0	14	2	22	0.00	0.06	0.01	0.06
360 - 369	0	5	0	13	0.00	0.02	0.00	0.04
370 - 379	0	6	1	6	0.00	0.03	0.00	0.02
380 - 389	0	2	0	12	0.00	0.01	0.00	0.04
390 - 399	0	1	0	1	0.00	0.00	0.00	0.00
400 - 409	0	2	0	0	0.00	0.01	0.00	0.00
410 - 419	0	2	0	1	0.00	0.01	0.00	0.00
420 - 429	0	0	0	0	0.00	0.00	0.00	0.00
430 - 439	0	0	0	0	0.00	0.00	0.00	0.00
440 - 449	0	0	0	0	0.00	0.00	0.00	0.00
450 - 459	0	0	0	0	0.00	0.00	0.00	0.00
460 - 469	0	0	0	0	0.00	0.00	0.00	0.00
470 - 479	0	0	0	0	0.00	0.00	0.00	0.00
Total	42	224	279	339				
<150	11	2	9	2	0.26	0.01	0.03	0.01
150-269	29	60	169	9	0.69	0.27	0.61	0.03
270-319	2	101	80	103	0.05	0.45	0.29	0.30
≥320	0	61	21	225	0.00	0.27	0.08	0.66

Appendix C3.—Summary of Arctic grayling sampled within portions of the East Fork Gulkana River during 1990 – 1992 (Bosch 1995) and 2002. Samples from 1990-1992 are composed of all fish sampled once during July and August and 2002 fish are all fish that were sampled once during late June and early July.

Length Category	Sample size (n)				Proportion of Sample			
	1990	1991	1992	2002	1990	1991	1992	2002
100 - 109	0	0	0	0	0.00	0.00	0.00	0.00
110 - 119	0	0	0	0	0.00	0.00	0.00	0.00
120 - 129	0	0	0	0	0.00	0.00	0.00	0.00
130 - 139	0	0	0	0	0.00	0.00	0.00	0.00
140 - 149	0	1	0	0	0.00	0.00	0.00	0.00
150 - 159	2	1	0	0	0.02	0.00	0.00	0.00
160 - 169	0	0	0	0	0.00	0.00	0.00	0.00
170 - 179	0	0	0	0	0.00	0.00	0.00	0.00
180 - 189	4	1	0	0	0.04	0.00	0.00	0.00
190 - 199	1	0	0	0	0.01	0.00	0.00	0.00
200 - 209	6	1	1	0	0.05	0.00	0.01	0.00
210 - 219	10	5	3	0	0.09	0.02	0.02	0.00
220 - 229	6	7	2	0	0.05	0.03	0.01	0.00
230 - 239	7	17	6	0	0.06	0.07	0.03	0.00
240 - 249	12	12	13	1	0.11	0.05	0.07	0.01
250 - 259	7	24	6	1	0.06	0.10	0.03	0.01
260 - 269	7	15	5	1	0.06	0.06	0.03	0.01
270 - 279	5	16	5	3	0.04	0.06	0.03	0.03
280 - 289	5	19	19	2	0.04	0.08	0.11	0.02
290 - 299	2	39	17	2	0.02	0.16	0.09	0.02
300 - 309	4	29	21	5	0.04	0.12	0.12	0.05
310 - 319	1	12	26	1	0.01	0.05	0.14	0.01
320 - 329	7	7	16	9	0.06	0.03	0.09	0.09
330 - 339	9	11	7	14	0.08	0.04	0.04	0.14
340 - 349	6	10	8	9	0.05	0.04	0.04	0.09
350 - 359	4	4	10	10	0.04	0.02	0.06	0.10
360 - 369	3	4	3	6	0.03	0.02	0.02	0.06
370 - 379	1	7	5	8	0.01	0.03	0.03	0.08
380 - 389	1	4	2	10	0.01	0.02	0.01	0.10
390 - 399	1	0	2	7	0.01	0.00	0.01	0.07
400 - 409	0	1	1	5	0.00	0.00	0.01	0.05
410 - 419	0	0	0	0	0.00	0.00	0.00	0.00
420 - 429	0	0	1	3	0.00	0.00	0.01	0.03
430 - 439	1	0	1	0	0.01	0.00	0.01	0.00
440 - 449	0	0	0	0	0.00	0.00	0.00	0.00
450 - 459	0	0	0	0	0.00	0.00	0.00	0.00
460 - 469	0	0	0	0	0.00	0.00	0.00	0.00
470 - 479	0	0	0	0	0.00	0.00	0.00	0.00
Total	112	247	180	97				
<150	0	1	0	0	0.00	0.00	0.00	0.00
150-269	62	83	36	3	0.55	0.34	0.20	0.03
270-319	17	115	88	13	0.15	0.47	0.49	0.13
≥320	33	48	56	81	0.29	0.19	0.31	0.84

Appendix C4.—Summary statistics of all Arctic grayling sampled and aged in the upper Gulkana River study area, 2002.

Age Category	Sample size (n)	Proportion of sample	Mean length (mm FL)	Range (mm FL)	SD (mm FL)
1	4	0.01	132	110 - 162	22
2	3	0.01	178	161 - 203	22
3	60	0.12	268	183 - 381	40
4	169	0.33	321	212 - 389	29
5	157	0.30	333	226 - 405	28
6	71	0.14	348	271 - 420	32
7	28	0.05	372	312 - 426	29
8	15	0.03	363	302 - 403	32
9	3	0.01	397	384 - 415	16
10	5	0.01	399	372 - 414	17
Total	515	1.0			
< 5		0.46			
≥ 5		0.24			

APPENDIX D
DATA FILE LISTING

Appendix D1.—Data files^a for all Arctic grayling sampled in the Chena and Chatanika rivers, 2002.

Data file	Description
Upper Gulkana grayling data-1990 to 1992.xls	Sample data from Upper Gulkana River, 1990-1992.
Upper Gulkana grayling data-2002.xls	Sample data from Upper Gulkana River, 2002.

^a Data files are archived at and are available from the Alaska Department of Fish and Game, Sport Fish Division, Research and Technical Services, 333 Raspberry Road, Anchorage, Alaska 99518-1599.